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Food systems for delivering nutritious and sustainable diets: Perspectives from the global network of science academies

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1. Nutritious and sustainable diets: the challenge

The need to provide adequate and nutritious food for everybody while preserving natural resources and mitigating climate change is recognised as one of the greatest challenges of our time. The challenges, however, cover sustainable production and sustainable consumption: the need to produce foods underpinning healthy diets, without over-consuming or wasting food. Unhealthy diets are associated with malnutrition, which encompasses undernutrition, overconsumption leading to obesity, and the consumption of low quality diets lacking essential nutrients. The problems associated with unhealthy diets are experienced in different measure by all countries. At present, the number of people affected is increasing: 820 million people have insufficient food, a rise from previous years, partly due to conflicts and the effects of extreme weather events (FAO, 2018). At the same time, the increasing consumption of calorie-rich diets is responsible for a worrying rise in the incidence of obesity and related non-communicable diseases. Malnutrition is a factor in one in five preventable deaths (Naghavi et al., 2017).

Food systems - which include food production, processing, storage and consumption - are also responsible for environmental degradation in terms of emission of greenhouse gases, misuse and pollution of natural resources, degradation of ecosystems and loss of biodiversity (Frank et al., 2018; Willett et al., 2019). This situation is unsustainable, and some of the damage is irreversible. A fundamental and rapid change is needed to meet food and nutrition security targets and improve health outcomes, while staying within planetary boundaries. This needs to happen within the overarching framework of the United Nations Sustainable Development Goals (SDGs): nobody should be left behind.

The task ahead is very ambitious, and requires strong political commitment and effective coordination at local, regional and global levels. It also accentuates many long-standing questions. What are the key knowledge gaps to sustainably achieve food and nutrition security for all? What are the main scientific challenges and opportunities? What are the key priorities in science to inform policy? And what is the most effective way of gathering and mobilising existing evidence and human resources to support this transformation?

The InterAcademy Partnership (IAP[1]) sought to capitalise on its membership of over 130 academies of science and medicine to develop a systematic process to frame and synthesize available scientific evidence at national, regional and global levels to support the transformation of food systems to deliver sustainable, nutritious diets. Four parallel working groups were established following nominations of experts across scientific disciplines by the regional networks of science academies: the Network of African Science Academies (NASAC); the Association of Academies and Societies of Sciences in Asia (AASSA); the Inter-American Network of Academies of Science (IANAS); and the European Academies' Science Advisory Council (EASAC). The analysis was bottom-up, with synthesis to develop common themes and recommendations, proposing an integrated, multidisciplinary approach that considers food and nutrition security and agriculture (FNSA) in the context of other key global challenges. The work resulted in the publication of five peer-reviewed reports: four regional studies and a fifth global synthesis set to discuss common trends and review scientific and policy issues that need to be addressed internationally (AASSA, 2018; EASAC, 2018; Bianchi et al., 2018; NASAC, 2018; IAP, 2018). The role of science academies in setting research and policy priorities is supported by the following qualities: 1) academies are merit-based institutions with members drawn from among leading scientists in all disciplines; 2) they focus on evidence based solutions to societal problems; and 3) their association in regional and global networks enables

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academies to address pressing global challenges while at the same time retaining awareness of national needs and priorities. The methodology has been described elsewhere (Fears et al., 2018, 2019; Canales Holzeis et al, 2019). The IAP FNSA initiative adds to a considerable body of work, but is distinctive in that it had the inclusive, specific objective of identifying key priorities in science, technology and innovation (including institutional and societal innovation as well as technical innovation). This perspective draws on the five IAP FNSA reports as a resource to identify some key points linking local-regional-global issues in the context of other recent literature to stimulate further discussion and help to catalyse further action by the academies.

2. What is the current FNSA status?

Africa, the Americas, the Asia/Pacific region and Europe differ in their agricultural production, access to knowledge and services, scientific infrastructure and research capabilities and in the degree to which policy making occurs at the regional level. But all regions also have similarities, particularly in having similar trends in consumption and nutrition behaviour, co-dependency on the environment and global trade. Moreover, a fragmentation of the food related research systems is observed in all the regions. Despite the widespread recognition of the importance of addressing the triple burden of malnutrition at a global scale, there was strong agreement between the regional WGs on the need to define much better the current extent of the problem. Suitable baseline data and regular monitoring are urgently required to inform effective policy actions and, to integrate interventions at the national and regional levels, it is essential to agree on the appropriate sampling and analysis methodologies to make data sets and findings comparable. Current knowledge gaps particularly affect vulnerable groups of the population – children, women, the elderly and migrants. The dearth of data is also responsible for distorted perceptions of the problem, noted EASAC. For example, undernourishment is generally considered a problem pertaining only to low-income countries. Recent evidence however suggests that a significant proportion of the households in high-income countries in Europe is not able to regularly access sufficient food to meet their calories requirement. The over-consumption of cheap, obesogenic diets which is fuelling a global public health crisis also disproportionally affects poor households. Obesity often coexists with an insufficient intake of essential micronutrients. The increasing disparity in wealth in most societies is exacerbating these problems (Loopstra, 2018).

A much clearer spatial picture of the current food and nutrition security status of populations is also needed. Disparities within a single country can be more marked than between countries. Generally, rural populations are more vulnerable than their urban counterparts in emerging economy countries. Addressing this inequality requires a better awareness of the problem and its root causes to guide policies and interventions. However, instances where regional intervention may be most appropriate because of shared challenges and needs were identified by both AASSA and IANAS. These “hotspots” for research and policy intervention include the Hindu Kush Himalaya Region (Rasul et al., 2019), an area stretching 3500 km which is home to about half of the people currently undernourished globally, and the Caribbean island states (Rhiney et al., 2017), which share fragile and undiversified economies and a very high vulnerability to extreme weather events. AASSA recommended working across the scientific community to develop a trans-national funding mechanism that prioritises research connected to FNSA for the region.

There was widespread agreement on the need to shift from a sectoral (usually agricultural production), top-down, ‘one-size-fits-all’ approach to one that is multi-disciplinary, multi-sectoral, bottom-up and context specific, recognising often profound differences between geographical areas and socio-economic groupings. In addition, it is important to determine the effectiveness and impact of specific interventions.

3. Sustainable food systems for nutrition and health

Since the completion of our work, several major reports have appeared, including from the IPCC (2018), Glopan (2018) and the EAT-Lancet Commission. Broadly, there is convergence of views on the principle of delivering sustainable, healthy diets, accessible by all, but there is much more to be done to define such diets and explore how to provide them. For example, the EAT-Lancet Commission recently described a universal reference diet, adaptable for specific cultural and nutritional needs, which would satisfy nutrition demands and improve human health sustainably. This diet would be mainly plant-based, with a low to moderate amount of seafood and poultry, and little or no red meat, processed meat, added sugar, refined grains, and starchy vegetables (Willett et al., 2019). This proposition has led to much controversy and is not universally accepted as a way forward. Clarification based on evidence of what constitutes a sustainable, healthy diet is required, as well as consideration of the economics of affordability of healthy diets by low income populations, which is often not taken into account. Also important is a shared understanding of the starting points and key impediments at local, national and regional levels, and due consideration of the synergies and trade-offs between different development priorities. This knowledge is essential to develop and implement workable solutions on a case by case basis.

Curbing meat production and consumption provides a relevant example of a policy objective with potentially conflicting developmental outcomes. Up to one billion smallholder farmers currently rely on livestock for their livelihood, and animal-based products represent an important source of nutrients for many more resource-poor people worldwide. In areas unsuitable for crop cultivation, livestock can be the only option for rural livelihoods. Livestock also provides farm labour and manure, and therefore is important for agricultural productivity in regions with low level of mechanisation and poor access to fertilisers. In addition, a significant proportion of the production of key crops takes place in mixed farming systems, especially in Africa (Salmon et al., 2018). Therefore, the transformation of food systems needs to occur as part of integrated approaches within the framework provided by the SDGs, with a strong focus on rural development and poverty reduction. Research priorities discussed by NASAC include increasing the efficiency of mixed farming systems, including the improvement of crops for dual use (for food and feed), pasture crops, improving existing sources of dietary protein and key nutrients, and introducing new nutritious foods. With respect to livestock, research on animal health, tolerance to environmental stresses and feed conversion is needed to minimise environmental impact. NASAC noted that frugal innovations that reduce the drudgery of farming and free up farmers’ time should also be pursued.

The delivery of healthy and sustainable diets requires a fundamental change to the composition of agricultural production. Diets are becoming increasingly homogeneous, with a limited number of species providing most of the calories consumed globally (Khoury et al., 2014). Resource-poor individuals in low-income countries in particular overly rely on a single carbohydrate source for their food supply. This dependence has negative implications for nutrition and as well as increasing the inherent risk and fragility of food systems. And while there is a global overproduction of grains, fats and sugar, the current production of vegetables, fruits and protein is insufficient to the meet nutritional demands of the global population (KC et al., 2018).

Research priorities for broadening the base of food supplies and increasing their nutritional value were discussed by all regions. A common goal is to focus attention on underutilised and indigenous crops, which are often more nutritious and better adapted to the local agronomic conditions (Chiurugwi et al., 2018). This is particularly important in areas where drought, heat and low soil fertility are significant agricultural constraints. Depending on the species, this may require crop domestication programmes which entail determining their basic biology, physiology and reproductive systems, all the way to

characterising genetic diversity in wild populations and developing advanced genetic and genomic resources for crop improvement.

EASAC noted that oceans represent a largely underdeveloped source of food. Current fishery practices targeting mostly predators have reached an upper limit and are unsustainable. However, marine environments provide only 2 percent of the calories and 15 percent of protein consumed by humans, and have the potential of supplying more. Improving the knowledge base for the sustainable harvest and culturing of marine resources at lower trophic levels and for exploring the potential for biomass provision would help reduce pressure on land and freshwater for food production.

All WGs discussed the development of novel foods and sources of nutrition. Research should aim to improve processing and packaging technologies to preserve the nutritional qualities of food and reduce waste, critical since an increasingly large proportion of the global population is urban. Food safety is another important aspect of nutrition, and research priorities in this field include the monitoring of bacterial, virus and chemical contamination; food authentication of origin and quality; protection of consumers' rights and the development of effective food surveillance technologies (Bianchi et al., 2018). Innovations must be fit for purpose. NASAC noted the importance for African countries of investing in low-cost diagnostics and food processing technologies that rely on renewable energy sources, since 80 percent of the continent's rural population is not connected to the electricity grid and has limited resources.

Other emerging areas in nutrition research discussed include the interaction between nutrition and genetics; metabolic phenotypes; individual responsiveness; personalised feedback/intervention; assessing the accuracy and specificity of self-collected data. A shift in nutrition studies to focus on foods and meals instead of on individual nutrients was recommended since the physical and chemical properties of foods affect the extent and the rate of nutrient digestion. In addition, foods contain compounds not classically considered nutrients (such as fibre, phytochemicals and bioactive proteins) that may impact human health (AASSA, 2018). The relationship between the gut microbiome and nutrition and health also warrants further attention.

Research to support the uptake of nutritionally balanced diets by consumers must include cognitive and social sciences. In African countries, for example, certain traditional foods, despite being nutritious, are associated with times of famine and have a stigma that must be overcome. Conversely, over-consumption of meat, dairy products and processed obesogenic foods is associated with affluence and improved social status in most cultures. Effective incentives to elicit positive behavioural change in consumers towards healthier diets are needed everywhere.

4. The preservation of natural resources

Food production is inextricably linked to the use and preservation of natural resources, in particular land, water, energy and ecosystems' biodiversity. Globally, agriculture accounts for 40 percent of the land surface, and 70 percent of freshwater withdrawals, mostly used for irrigation. The demand for water continues to grow - driven by population increases, urbanisation and economic growth, and changes in pattern use - and the majority of this increase is expected to take place in emerging economies (UN, 2018). A study combining the projected increase in water demand and urban water sources of 482 of the world's largest cities predicts that in over a quarter of the cities studied water demands will exceed surface-water availability. Furthermore, an additional 19 percent of the cities will experience a conflict between urban and agricultural sectors, since both sectors will be unable to obtain their projected demands (Flörke et al., 2018). Total demand for water taking into account other sectors, in particular energy production and industrial uses, is likely to soon exceed total resource availability in many parts of the world (Bianchi et al., 2018; UN, 2018).

In addition to problems related to water scarcity, water resources are becoming polluted, and the situation is expected to worsen in coming years, especially in low-income countries due to population increase, economic growth and poor water management practices. The leading cause of the deterioration of water resources is the degradation of ecosystems. Soils are critical in influencing water cycling through evaporation rates, water retention, and lower soil water storage. Increased runoff waters in degraded land leads to higher rates of soil erosion and to the contamination of water resources. Extreme weather events, and the risk of floods and drought are also increasing. Floods are predicted to affect 1.6 billion people by 2050 (from 1.2 billion today), while land degradation, desertification and drought are already considered the most significant category of “natural disaster” affecting today an estimated 1.8 billion people (UN, 2018). The loss of productive capacity of ecosystems and the increasing inability of populations to access an adequate level of resources are important components of increased mass migration, political instability and conflicts (IAP, 2018).

Challenges related to water use were discussed in all the regional IAP FNSA studies. Periodic droughts exacerbate water management problems, and high rates of deforestation are threatening water sources. IANAS identifies the inefficient management and contamination of water resources as one of the greatest environmental problems of the Americas (Bianchi et al., 2018). Although the continent has ample water resources, these are not distributed equally, and some countries are particularly vulnerable to both droughts and floods. In Asia and Oceania, AASSA described the fast fashion industry as a leading cause of competition for land and water with food production. Cotton, the most used raw material, is increasingly being grown in land previously devoted to the cultivation of food crops (Bick et al., 2018). The excessive use of water (cotton requires large amounts associated with its production) is unsustainable and the contamination of water resources with fertilisers, pesticides and untreated dyes represents a major environmental threat. Weak labour unions and legislation in many Asian countries lead to cheap manufacturing and labour costs, hazardous working conditions and low standards of occupational protection. Eighty billion pieces of new clothing are purchased each year, and this has created millions of tons of textile waste in landfills, and has fuelled an unregulated market of second-hand clothing in low-income countries (Bick et al., 2018). The inexpensive price of clothing does not account for either the environmental or human health costs associated with its production. All IAP FNSA networks also discussed the impact of policies promoting biofuel production on food production and over-exploitation of water resources. However, a by-product of biofuel production is high-protein animal feed, and this is usually ignored in economic and environmental models. As these examples show, there are still numerous research issues to clarify and resolve (IAP, 2018).

Equitable access to water and other resources is just as important as availability. NASAC noted that Africa is the most targeted continent for large-scale land transfers, usually involving fertile, accessible land close to populated areas with access to water and other resources (Anseeuw et al, 2016). These acquisitions, not always for food production, can lead to competition and conflict over access to land and water and often also displace smallholder farmers from the land they had occupied.

Since agriculture is the biggest sectoral user of freshwater, an overarching research goal is to improve the efficiency of water use. While improvements to irrigation practices are important, improving water use in rain-fed agricultural systems is likely to have a bigger impact since these currently account for the majority of production. These would also have the largest benefit in terms of poverty reduction (UN, 2018). Research areas include the improvement of crop varieties (including orphan crops) for increased water and nutrient use-efficiency; conservation agriculture practices; improvement of dryland agriculture; plant-soil microbiome interactions; water management, retention and storage innovations, including nature-based solutions recently reviewed by UN-Water (UN, 2018); the recycling of water (for example, in closed production systems); precision agriculture and the use of big data to support decision making. A shift is needed to focus on

productivity per total natural resources used rather than productivity per financial cost. In view of challenges associated with climate change, there is need to evaluate climate resilience throughout food systems and transform those systems to mitigate their global warming impact (Porter et al., 2017). Reducing waste in food systems is an important priority discussed by all IAP reports, as it represents a very significant cause of misuse of resources. An important step forward will be the adoption of the circular economy model of reducing, reusing and recycling in production.

Improving our understanding of the current use of and future demand for global resources is also a critical research objective. Future projections of global water demand, for example, are rendered uncertain by the limited data available, inconsistent data sets and the difficulty of quantitatively determining the interconnections between important environmental, social and political factors (Wada et al., 2016). These include climate change, changes in land use, population growth, technical innovations, political stability and the extent of international cooperation. Scientific scenarios must factor in predictable changes as well as acknowledge critical uncertainties. Their value lies as well in highlighting what the research agenda to fill key knowledge gaps should be, and to better understand and influence the most likely outcomes. Scenarios also help identify hotspots for intervention and enable an assessment of the trade-offs and synergies among different management options (Wada et al., 2016; UN, 2018).

5. From regional analysis to global priorities

The global IAP analysis was guided by three main principles. The first is the role of science and innovation to strengthen and safeguard the delivery of international public goods, intended as those which must be provided at a scale which is not attainable by individual countries and hence require collective action and coordination. These include the generation, use and exchange of scientific knowledge. The second principle is the need to understand international environmental and institutional risks in an increasingly uncertain and interconnected world. The need for a renewed and sustained engagement of science with the SDGs for addressing complex challenges and resolving potential conflicting goals constitutes the third principle. The plurality of interconnections between local and global systems, in particular with respect to issues related to land and water use, climate change and the health-nutrition-sustainability nexus were noted in previous sections and are discussed in more detail in the IAP Global report (IAP, 2018). The latter also addresses the importance of FNSA in multiple SDGs, in particular 3, 11, 12, 13, 14 and 15 as well as SDG 2. In addition, the IAP project itself is a good example of how SDG 17 (partnership) targets can be met by enhanced regional and global cooperation in science, technology and innovation.

Since all countries depend to some extent on trade to meet domestic food demands, global trade is a major factor in the sustainability of food systems, especially because the cost of food does not reflect the environmental and human resources needed for its production. A study on land and freshwater withdrawal of 160 traded food commodities indicated that about one-third of the use of these natural resources is linked to interregional trade. The results show that high-income countries are the principal users of agricultural land and water, which effectively means both a net transfer of these resources from low-income countries, and a displacement of the environmental cost of food production from importing to exporting countries. The authors recommend international cooperation for sustainable land and water use targeting both producers and consumers along global food supplies chains (Chen et al., 2018). International trade also distorts current GHGs footprint accounting, because emissions linked to food production are attributed to exporting countries, and not to those importing and consuming the commodities. Almost a third of resources used and a quarter of the global GHG emissions are displaced through trade (Wood et al., 2018). In Europe, meat and egg consumption represents the largest share of food supply emissions (Sandström et al., 2018).

The geographical divergence between food production and consumption is expected to grow. Accordingly, international trade will become increasingly important as a mechanism to balance needs and availability, and could play a role in reducing food insecurity, although the magnitude of this contribution is controversial (IFPRI, 2017). Research is required to clarify alternative options in developing trade policies, taking into account the role trade barriers for protecting small producers in resource-poor countries. Analysis of vulnerabilities in key regions, for example the Middle East, Central America and sub-Saharan Africa (d'Amour et al., 2016), indicates that a region-specific combination of national increases in agricultural productivity and diversification of trade partners and diets can decrease future food security risks.

Research priorities identified by the Global IAP study with respect to trade include: understanding non-tariff trade barriers, (such as food quality and safety attributes, and fair trade); food safety and the standardisation of traceability; understanding international price volatility in food markets to increase system resilience; exploring the correlation between individual and local risks to assess aggregate and global risks.

6. Science and innovation for global FNSA

The IAP FNSA initiative considered the generation of science and innovation, and the sharing of these resources across borders, as a global public good. All the regions made emphasis on developing a solid evidence base to inform effective policies, and on monitoring implemented policies and interventions, being mindful of possible unintended consequences. The research agenda needs to go beyond rural and agricultural development, integrating science, technology, engineering and social innovations for the transformation of food systems. Science also needs to address the governance and coordination of policies. A new more effective science and policy interface in the field of food and nutrition security and agriculture is called for by the IAP, in support of evidence-based policies, including science policy.

Science and innovation should focus on all food systems: from smallholder production to sophisticated food value chains and the bioeconomy. Responsible innovation, accessible to its intended users, is critical in all sectors, and include, for example, avoiding introducing new barriers to access by small-scale farmers to newly commercialised seeds. It is important to capitalise on emerging technologies, such as the novel bioscience-based approaches to improve plant and animal breeding and the suite of activities encompassed within precision agriculture, and at the same time address the challenges that these advances introduce for regulation, education and extension.

The long-term commitment to basic research is essential to sustain innovation and open new frontiers, and this includes commitment to long-term funding. All the IAP WGs noted the large amount of variation in the scientific capacity within all regions. For many countries, it is too costly to develop the required scientific infrastructure and human capacity for large or sustained research programmes, and therefore it is important to reduce competition and duplication to avoid the fragmentation of efforts, and focus instead on increasing international cooperation in research for shared objectives. It is equally important to attract talented young people to form the next generation of researchers. All the reports noted the general low level of collaboration between universities and research institutes and weak interaction between researchers and the private sector and extension services. A comprehensive global research system on food, nutrition and agriculture, drawing on a wide range of science disciplines and data, still needs to evolve. Science academies can play a key role in shaping it.

Vision without action is a daydream, and action without a vision is a nightmare, a Japanese proverb goes. IAP urges strong political commitment, leadership and coordination for addressing today's challenges. All the sectors of society need to take part in transforming the way we produce and consume food.

key IAP FNSA recommendations:

1. Developing sustainable food and nutrition systems, taking a systems perspective to deliver health and well-being, linked to transformation towards the circular economy and bioeconomy.
2. Emphasising the transformation to a healthy diet and good nutrition.
3. Understanding food production and utilization issues, covering considerations of efficiency, sustainability, climate risks and diversity of resources.
4. Capitalising on opportunities coming within range in the biosciences and other rapidly advancing sciences.
5. Addressing the food-energy-nutrients-water-health nexus.
6. Promoting activity at the science-policy interfaces and reconciling policy disconnects.
7. Consolidating and coordinating international science advisory mechanisms. Constituting an International Panel for Food and Nutrition Security and Agriculture, thereby serving to strengthen science strategies in these fields of vital importance for the world population and support international governance mechanisms and policy with evidence.

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